

WHENCE THE NGP?

Richard G. Gann
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8664 USA
Tel: (301) 975-6866; Fax: (301) 975-3652; e-mail: rggann@nist.gov

BACKGROUND

In its decade of research (1997-2006), the United States Department of Defense's Next Generation Fire Suppression Technology Program (NGP) re-vitalized the field of fire suppression science. The NGP arose as a result of a discovery that garnered the Nobel Prize for two accomplished chemists and legislation that turned science into public policy. A forthcoming book tells the story of how the NGP came about, what research was performed, how it modernized the thinking in the field, and the technical findings that emerged related to fire suppression in aircraft.¹

THE EVOLUTION OF FIRE SUPPRESSION

The ability to control fire is universally and exclusively human. The history of that controlled use is also the history of civilization.² While individuals likely recognized the first principles of fire control, it was the rise of organized societies that led to structured activities and, later, products to mitigate the unwanted outcomes of fires. The application of chemicals to control fires, now a mainstay of modern society, has a rich history.³

Some 3 million to 5 million years ago, small nomadic groups of pre-humans observed the nature of fire. While they could see its destructive power, they soon recognized its benefits as well: trapping animals, cooking food, providing warmth. They no doubt observed that rain made the fires stop, and some might have even noticed that there were few fires following a rainstorm. By about 400,000 years ago, the sparse nomadic clusters of homo erectus had learned how to "capture" fire. Since the initial source of this benefactor occurred only episodically, they spent considerable effort to keep the fire from going out.

The citizens of Rome appear to have had the first formal code for fire control. Among other provisions, tenants were often required to have a bucket of water in their flats, and intentional fires within those flats were often forbidden. The city of Rome also had fire patrols and fire bucket brigades. Nonetheless, over 40 large conflagrations were recorded between 31 BC and 410 AD. Of course, virtually none of this existed in the Empire outside of the capital city.

Pre-industrial Europe continued to have numerous major urban conflagrations, even past the Middle Ages. Buckets of water were still the only major means for stopping fire spread. Despite the invention of the rollable fire hose and combustion-powered water pumps, large city fires continued to be a problem up till the San Francisco fire of 1906, just 100 years ago.

During the 19th century, the steam-powered, self-propelled fire engine enabled bringing water to the fire; and automatic sprinklers began bringing the water directly into the building.⁴ This provided faster response and further containment of the fire damage. What remained was the development of technology to assure the safety of the contents.

THE RISE OF THE HALONS

Just after the turn of the 20th century, a process for the electrolysis of salt water enabled a large supply of inexpensive chlorine. This soon was used to make carbon tetrachloride (CCl₄), which soon came into use as a fire suppressant. CCl₄ was the first clean agent, in that, unlike water, it caused no damage to a building or its contents and left no residue itself. It was also the first halon, halon 104 (see below). Like water, it was squirted at the fire or was thrown at the fire in frangible containers, called grenades. Concerns soon arose about its toxic effects on firefighters and others at the fire scene. Nonetheless, the use of carbon tetrachloride continued through World War II, in which it was used extensively.⁵

By this time, bromine, another element in the same periodic table column as chlorine was also considered as a possible component of fire suppressant compounds. Methyl bromide (halon 1001) appeared in the 1930s, but was found to be more toxic than CCl₄. The Germans developed and used chlorobromomethane (halon 1011) as their clean suppressant of choice during World War II. It was more efficient than halon 104, and after the war it found broad use elsewhere.

Recognition of the need to consider agent toxicity was another milestone in the evolution of fire suppression technology. Now the suppressant itself would need to be examined for its possible effects on fire fighters and building occupants. Some selection from among the effective halocarbons was in order, and toxicity was the new criterion on the list.

In 1948, the U.S. Army commissioned the Purdue Research Foundation to search for a suppressant of high fire suppression efficiency but low toxicity.⁶ The Army coined the term “halon,” short for halogenated hydrocarbon, and devised the naming system that shows the numbers of the types of atoms in the molecule in the order: carbon, fluorine, chlorine, bromine, iodine (terminal zeroes dropped). During the 1960s and 1970s, two of the compounds tested emerged as commercial successes. Halon 1301 (CF₃Br) found widespread use as a total flooding agent, i.e., it dispersed throughout a space, quenching flames regardless of location. Halon 1211 (CF₂ClBr) became the predominant streaming agent.

As the use of these chemicals increased, there were additional research, testing, and assessments performed, for example:

- In the 1960s and 1970s, extensive engineering studies developed information needed to design systems for implementation of the halons.
- In 1973, the National Fire Protection Association issued Standard 12A for halon 1301 systems and Standard 12B for halon 1211 systems. Much of the data to support these standards came from research and testing conducted at industrial laboratories, such as Factory Mutual, ICI, and DuPont.^{5,7}

- In the 1970s, research at the U.S. Bureau of Mines⁸ was directed at obtaining a better understanding of the mechanisms of halon 1301 that could guide its use as a suppressant for methane explosions in mines. At the U.S. Naval Research Laboratory⁹, related fundamental research on halon 1301 was sponsored by the Naval Air Systems Command as part of a search for a more efficient extinguishing agent for in-flight fires.
- In 1972, the U.S. National Academy of Sciences held a Symposium to examine the state of knowledge on the toxicity and engineering applications of the halons.¹⁰
- In 1975, a symposium was held to examine the basic processes occurring in flames inhibited by the halons, leading to the inference of the mechanisms of flame suppression.¹¹

Halon 1301 had turned out to be very efficient at quenching fires, as shown in Table 1. Because of the small amount needed, because it did no harm if deployed accidentally, and because it could put fires out before any significant damage occurred, halon 1301 systems were increasingly installed to protect contents of special value and spaces in which storage weight and volume were at a premium. By the 1980s, most computer rooms, nearly all commercial and military aircraft, and numerous museums were protected by these halon systems. As a footnote, their acceptance signaled the end of the use of CCl₄ as a fire suppressant, a prophetic result, as it was later determined that carbon tetrachloride was a carcinogen.

Table 1. Flame Quenching Effectiveness of Halon 1301 and Other Chemicals (mole %)

Flame/Fire	Halon 1301	HFC-227 ea	Carbon Dioxide
Small diffusion flame	3.1 ¹²	6.6	21 ¹³
Pool Fire (10 s extinguishment)	4	8	--
Wood	3.0	5.8 ¹⁴	--
Fiberglas/polyester resin	3.5	--	--

1.1 THE ATMOSPHERIC THREAT

In 1974, F. Sherwood Rowland and Mario Molina published a paper showing that certain chlorinated compounds (chlorofluorocarbons, or CFCs), while playing beneficial roles as, e.g., coolants and solvents, posed a threat to the global environment by catalyzing the conversion of ozone to ordinary oxygen, which provided no protection to life on earth from harmful ultraviolet radiation.¹⁵ Subsequent atmospheric measurements and modeling showed that the threat was real, and Rowland and Molina were awarded the Nobel Prize in Chemistry in 1995.

The nations of the world moved toward an international agreement to protect the environment, the Montreal Protocol on Substances That Deplete the Ozone Layer.¹⁶ As the agreement was being forged, it was realized that some brominated compounds were potentially even more dangerous than their chlorinated cousins,¹⁷ and the halons (with the name mistakenly used to mean only brominated and chlorinated perhalocarbons) were named explicitly. Their production was curtailed sharply in amendments to the U.S. Clean Air Act of 1990. As of January 1, 1994, under the 1992 Copenhagen Amendments to the Montreal Protocol, halon 1301 was banned from

production, except in certain developing countries and countries whose economies were in transition.

This was a new paradigm. The world had decided that the global threat took priority over local issues of fire safety, which presumably could be provided in some other manner.

Even as the search for alternative fire suppressants was underway, usage was declining markedly. By the early 1990s, alternatives for firefighter training and system testing had been identified. A number of facilities converted to automatic sprinklers, and, in some cases, fire suppression became unnecessary.

The early replacements for halon 1301 were identified during the quest for replacement refrigerants. Some of these, such as the hydrochlorofluorocarbons (HCFCs) were ozone depleters themselves and were less favorable choices. An early brominated compound, CHF_2Br (halon 1201), was found to have a fire suppression efficiency comparable to halon 1301, but even though its ODP value was far lower than that of halon 1301, it was above that permitted by the U.S. Clean Air Act. For a variety of applications, the choices were hydrofluorocarbons, or HFCs, which have zero ozone depletion potential (ODP) values.^{i,18} These were far less effective fire suppressants, but appeared to have no harmful atmospheric effects. Other commercial products included mixtures of inert gases, also less efficient suppressants, and blends of halocarbons.

The U.S. Department of Defense (DoD) had come to rely heavily on halon 1301 systems, in particular, for fire protection in its numerous ground, sea, and air weapons systems. Committed to reducing its dependence on halon 1301, the DoD totally revamped its fire suppression system testing, certification, and recycling procedures. From 1993 to 1998, the DoD conducted a major program on ozone-depleting substances (ODSs), the Technology Development Program (TDP). It focused on the identification of near-term, environmentally friendly, and user-safe alternative fluids, developed by industry, that were either readily available or could enter commercial production in the near future. The TDP research was successful in identifying replacements for the non-firefighting ODSs.

However, the best available replacements for halon 1301 were two HFCs: $\text{C}_2\text{F}_5\text{H}$ (HFC-125) onboard aircraft and $\text{C}_3\text{F}_7\text{H}$ (HFC-227ea) for shipboard use.¹⁹ These were substantially less efficient fire suppressants, requiring two to three times the mass and storage volume. This would severely compromise their implementation, given the tight weight and space limitations. In addition, their use would result in a post-deployment atmosphere containing appreciable concentrations of acid gases that was not suitable for human occupancy and that could chemically attack metals, synthetic materials, and electronics. Some engineering was conducted to adapt the use of these chemicals for some platforms. One alternative approach that showed some promise was the use of solid propellant fire extinguishers, similar to the units developed for automobile airbags. Nonetheless, the DoD decided to formulate a successive research program focused on improved options for fire suppression in fielded weapons systems.

ⁱ The ozone depletion potential of a gas is defined as the change in total ozone per unit mass emission of the gas, relative to the change in total ozone per unit emission of CFC-11 (CFCl_3).

Even before replacements for the CFCs and halons could be implemented, an additional threat to the global environment was identified: global warming. Compounds that increased absorption of infrared radiation from the planet surface and re-radiated energy back to that surface would lead to warming of the earth. It was soon realized that most of the halon 1301 replacements fell into this category.²⁰ This added yet another constraint to the search for the successors to the halons.

As an interim measure, the DoD (among other organizations and governments in about 20 countries²¹) had created "banks" of halons 1301 and 1211 as a means of continuing protection during the search for alternatives. The security of such banks, however, is not assured. The few essential uses for ODSs allowed by international agreement were conditional on continued efforts to find environmentally benign alternatives. Furthermore, in 1994, a United Nations Environmental Program report identified four principal actions that would speed the return of the ozone layer to its prior level. The second most effective of these was the non-release of all halons currently in existing equipment.²² This was a signal that the world was watching the effort to identify and implement alternatives to the halons and that an accelerated phase-out was a clear possibility. In related activity, research was underway to develop processes for the economical conversion of the halogenated hydrocarbons into other useful chemicals.

HISTORY OF THE NGP

To ensure the safety and mission capability of U.S. forces and to preclude any long-term halon *use restriction* impacts, a new DoD technology program was formulated.²³ The Next Generation Fire Suppression Technology Strategy Program (NGP) had as its goal:

"to develop and demonstrate, by 2004, retrofitable, economically feasible, environmentally acceptable, and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in existing weapons systems."

The emphasis was on *retrofit*, i.e., developing technologies that could readily be installed on existing weapons systems.ⁱⁱ This led to an oversimplification of the task, by some observers, as a search for a "drop-in" replacement chemical. In fact, the NGP included examination of technologies that could improve the performance of a chemical whose inherent fire suppression efficiency was only mediocre relative to that of halon 1301, approaches that used granular materials, rather than compressed fluids, and even technologies that used no active suppressant at all. The Program would be complete when the generic know-how existed to design cost-effective alternates to halon 1301 systems.

The concept of the NGP was created by Dr. Donald Dix and Mr. Paul Piscopo of the Office of the Secretary of Defense. Planning began in 1994, and the Program was initiated in fiscal year 1997. Oversight and guidance of the Program was provided by a DoD Halon Alternatives Research and Development Steering Group. The membership consisted of representatives from

ⁱⁱ Although not explicit in the goal statement, the presumption was that the new science and improved approaches to fire suppression would also be adaptable to the design of future weapons systems. The economics of adapting the new knowledge would likely be more restrictive for an existing aircraft, ship, or ground vehicle; and it was recognized that some expensive-to-retrofit technologies might not be pursued within the NGP, although they might be more viable economically for new weapons systems.

the DoD agencies with responsibility for fire suppression research and development, testing, and implementation of new technology. The U. S. Environmental Protection Agency (EPA), which approved suppressants based on their environmental impact and safety during exposure, provided a liaison to monitor DoD development of alternatives to halon 1301. The principal sponsor of the NGP was the DoD Strategic Environmental Research and Development Program (SERDP).

I had the privilege of serving as the Technical Program Manager for the duration of the NGP. Providing additional scientific and pragmatic expertise was a Technical Coordinating Committee, whose membership evolved over the life of the Program: Mr. Lawrence Ash and then Mr. Donald Bein of the Naval Air Systems Command, Dr. Michael Bennett of the Air Force Research Laboratory and then Mr. Martin Lentz of the Air Force's 46th Test Wing, Dr. William Grosshandler of the National Institute of Standards and Technology, Dr. Andrzej Miziolek of the Army Research Laboratory, and Dr. Ronald Sheinson of the Naval Research Laboratory. Administrative support for the NGP was provided by Gamboa International Corporation.

The NGP was a closely integrated research program whose potential for success was maximized by bringing together the nation's best scientists and researchers in fire suppression and associated technologies, with extensive interactions between the technical disciplines and the project principal investigators. The research was organized into six technical thrusts:

1. Risk Assessment and Selection Methodology
2. Fire Suppression Principles
3. Technology Testing Methodologies.
4. New Suppression Concepts
5. Emerging Technology Advancement
6. Suppression Optimization

While the early NGP research was underway, the military services were pursuing solutions, based on TDP technology, for some of the DoD platforms. The Army had identified fire suppression technologies for both current and planned ground vehicles that needed only engineering for implementation. The Navy had no plans to retrofit current ships and had initiated a research program on water mist technology for forward fit.

However, the aircraft safety and survivability engineering teams from all three Military Services had fire suppression needs for engine nacelles and dry bays that were not being addressed by Science and Technology (S&T) efforts outside the NGP. Thus, in 1999, the goal for the NGP was refined:

"to develop and demonstrate technology for economically feasible, environmentally acceptable and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in aircraft." ²⁴

This revised statement included application to both existing and planned aircraft. The deliverables, in addition to a well-documented science basis, were to be:

1. Identification of the best chemicals to consider as alternatives to halon 1301 for extinguishing in-flight fires in engine nacelles and dry bays;
2. Guidance for engineering the fire suppression system to obtain the most efficient use of the suppressant chemicals;
3. Development of practicable non-fluid-based suppression technologies; and
4. Creation of means for deciding among candidate solutions for a given application.

The documentation was to include not only those tests, models, and computations that led to improved firefighting capability, but also those that were not promising. This documentation would then serve as a resource for those who entered the field in future times.

Realization of the difficulty in searching for an effective fire suppressant system comes from viewing an aircraft engine nacelle (Figure 1).ⁱⁱⁱ A dry bay is no less complex.

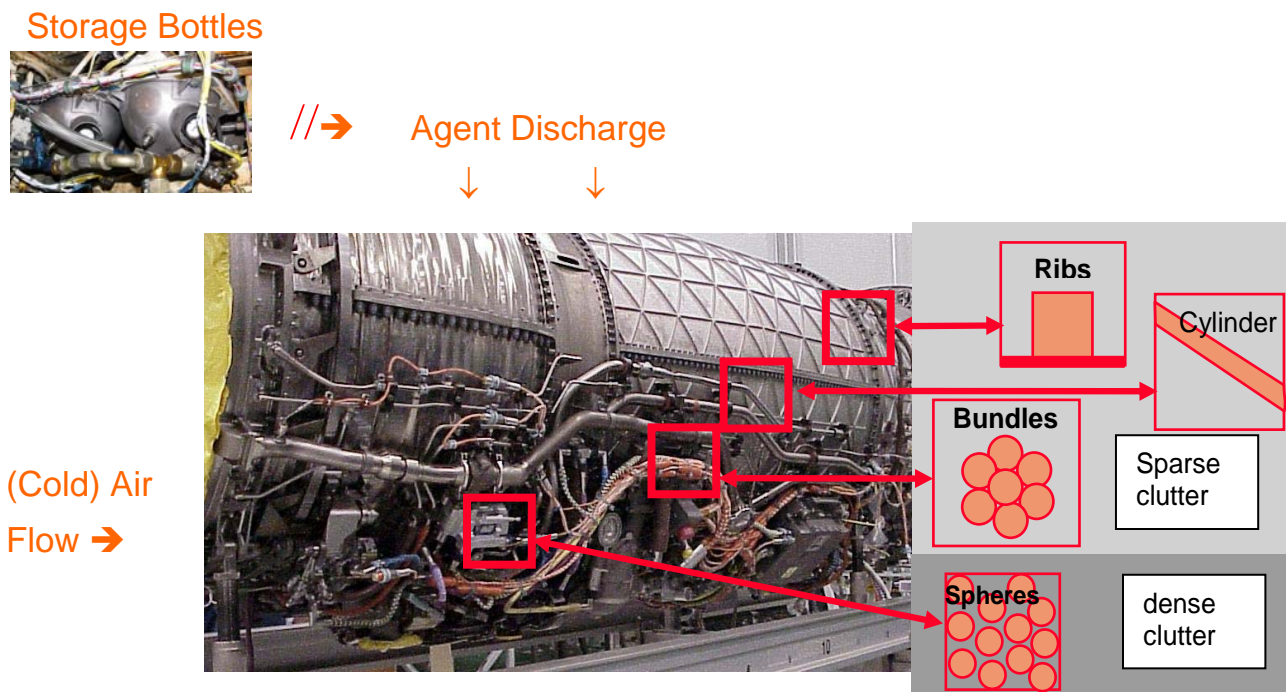


Figure 1. Interior of an Aircraft Engine Nacelle.

The suppressant is injected, at a small number of points, into this annular space between the pictured engine exterior and the outer, cylindrical housing (not shown in the figure). The agent must fill the annulus, reach all the nooks and crannies, and put out the flames from a fire in any location, all before the cold air flow flushes the chemical from the nacelle.

Scientists and engineers were thus looking for compounds that had high fire suppression efficiency, effective quenching of flame re-ignition, low ozone depletion potential (ODP), low

ⁱⁱⁱ An engine nacelle is the housing of an aircraft jet engine. The exterior is aerodynamically smooth, while the interior has ribbing that provides the structural strength for the nacelle.

global warming potential (GWP)^{iv}, short atmospheric lifetime^v, low suppressant residue, low electrical conductivity, low corrosivity to metals, high compatibility with polymeric materials, stability under long-term storage, low toxicity of the chemical and its combustion and decomposition products, and high speed of dispersion.

The research on advanced fire suppression processes, technologies, and fluids encompassed 42 interrelated projects. Many of these were outlined in the original NGP Strategy Document and were structured by successful proposals in an open competition. These were complemented by solicitations for proposals of new ideas. The remaining projects were commissioned by the Technical Coordinating Committee, with approval of the DoD Halon Alternatives Steering Group and the sponsor, based on the outcome of the prior projects and newly acquired understanding of the additional research needed to meet the NGP goal.

Figures 2 through 5 depict the relationships between the projects and their relationships to the NGP deliverables. Cyan boxes are projects that were performed, red boxes indicate projects that were planned but not performed, the yellow box represents work in progress elsewhere at the time of this book, and orange boxes depict the deliverables. An asterisk (*) notes projects that appear more than once.

As the research progressed, the findings have been published in archival journals, issued as DoD reports, and presented at technical meetings. Prominent among these meetings were the annual Halon Options Technical Working Conferences (HOTWC), founded by Dr. Robert Tapscott of the New Mexico Engineering Research Institute. Attendance at these meetings included domestic and international representatives of weapons platforms manufacturers, the military services' safety and survivability teams, civilian customer for fire suppression systems, fire suppression systems manufacturers, and members of the national and international fire research and engineering communities. Eventually, when this key meeting lost its original host, the NGP assumed the responsibility for the organization and conduct of the meetings and for the publication of the cumulative papers.²⁵

Ten years later, the NGP is preparing to complete its task. The NGP papers in this Conference demonstrate the advances in understanding of how best to deliver a flame extinguishing chemical, how an agent works when it reaches the fire, how to examine the seemingly infinite number of chemicals, which properties of fluids make for effective and safe fire suppression, what chemicals work well and which don't, better ways to engineer non-fluid suppression systems, and how to evaluate the true cost of a new suppression system.

^{iv} The global warming potential of a gas is defined as the change in irradiance at the tropopause (the boundary between the stratosphere and the troposphere) per mass of the gas emitted relative to the change in irradiance per mass of carbon dioxide.

^v Faced with two chemically different effects of compounds on the environment, it was recognized that a broad approach to minimizing atmospheric perturbations was advisable. Atmospheric lifetime is an indicator of the potential for released chemicals to be degraded or removed from the environment before they could effect harm. It is the time, after its initial emission into the atmosphere, it takes for the compound to decay to 1/e (37 %) of its original concentration.

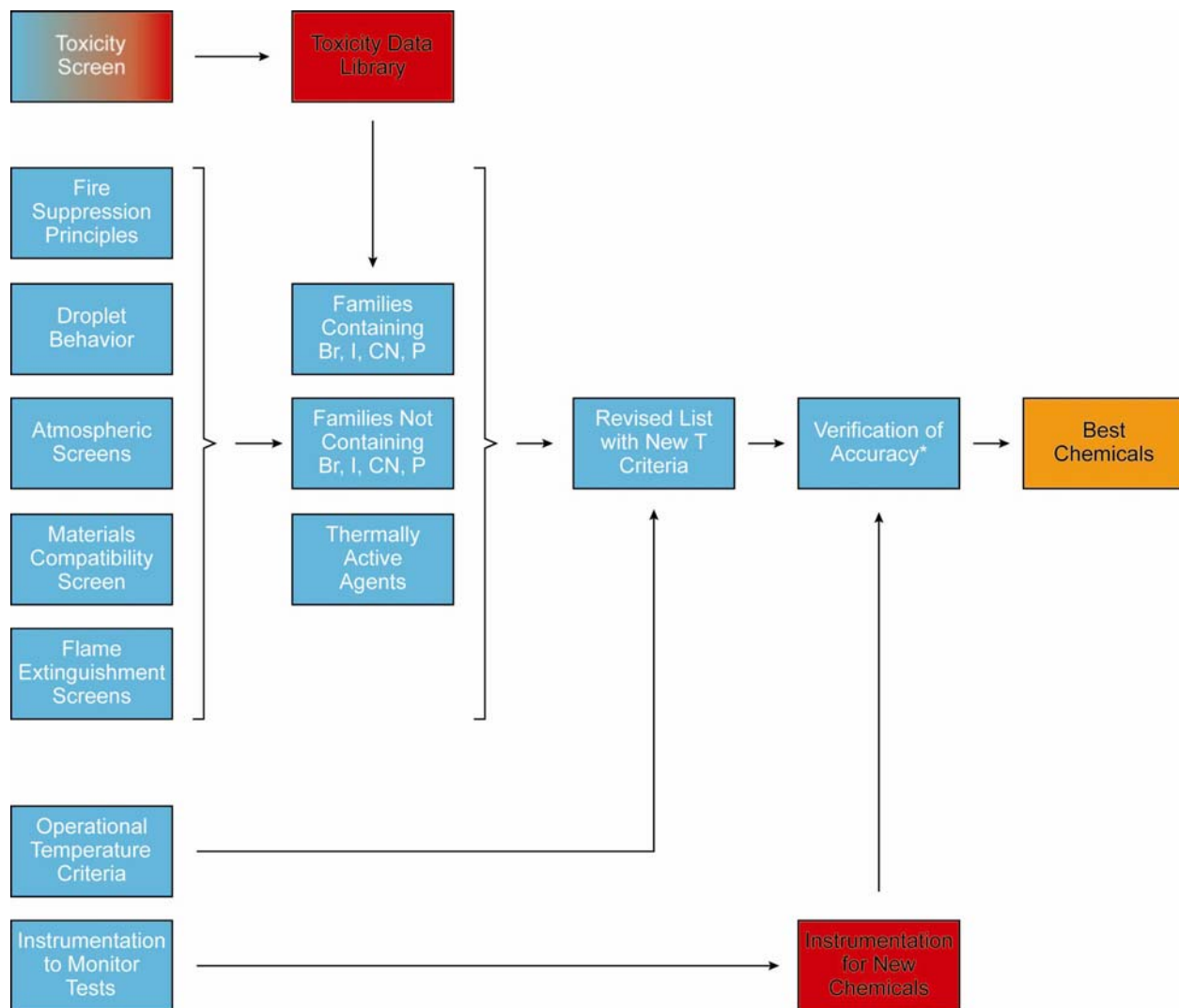


Figure 2. Projects Contributing to Deliverable 1: Best Alternative Suppressant Chemicals

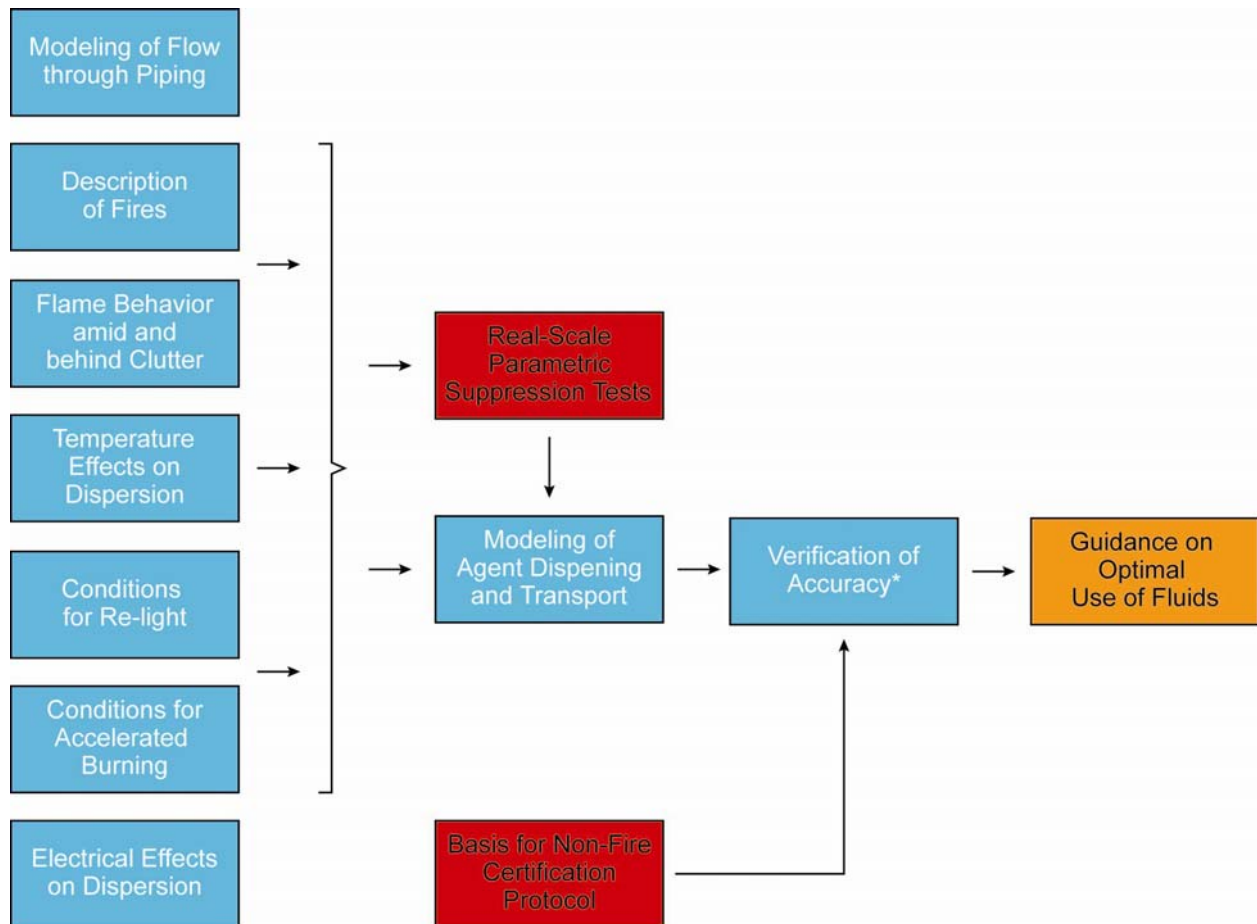


Figure 1. Projects Contributing to Deliverable 2: Alternative Extinguishment Technologies.



Figure 2. Projects Contributing to Deliverable 3: Alternative Extinguishment



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